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Surface movements of earthworms in agricultural land

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With 2 figures

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1. Introduction

Earthworms are generally regarded as relatively sedentary organisms, movement through burrowing activity within the soil being emphasised in past literature. However, as pointed out by SCHWERT (1980), this seemingly sedentary nature of earthworms is misleading.

According to LEE (1985), it is likely that all species of earthworms emerge from the soil and move about over the surface on the ground, some species emerging frequently and some only rarely. This above ground activity usually occurs at night, the day-time being spent below ground. After surface activity, most earthworms return to their own burrows. Some individuals, however, re-enter the soil elsewhere and it is probable that population dispersal largely results from gradual spread in this manner. Indeed, the success of certain immigrant earthworm species introduced by humans has been related to their greater tendency to emerge from the soil and move about (BOUCHÉ, 1976). This phenomenon of active dispersal over the surface has been further considered. SCHWERT (1980), for example, suggests that under certain conditions surfaced lumbricid earthworms can migrate rapidly and for long distances, and that they can quickly re-enter the soil in areas where it is sufficiently porous.

As far as rates of movement are concerned, previous investigations have tended to focus on the dispersal rates of earthworm populations within the soil habitat (for review see LEE, 1985). Thus, information concerning the actual distances travelled by individual earthworms when above ground is sparse. The aim of our investigation is to provide quantitative data for the distances travelled over the surface by individual earthworms under natural conditions. In this preliminary report, we make use of the surface trails of earthworms as a simple yet effective method for examining earthworm surface movements. In particular, we consider the surface trails of *Lumbricus terrestris* L., 1758, in agricultural land.

2. Materials and methods

The investigation was conducted on arable land belonging to the National Institute of Agricultural Science, at Foulum, Jutland, Denmark. The region has a sandy-loam soil which has a mean pH of 6.7, and the average mull depth is 53 cm. The soil texture, as determined from 0–20 cm depth samples, is 7.5 % clay, 9.5 % silt, 45.5 % fine sand, 34.5 % coarse sand, and 3.0 % humus.

Observations were carried out on the 23 and 24 October 1987, covering the day-time periods 14.00–20.00 h on day 1, and 10.00–16.00 h on day 2. During the week preceding the investigation, very little precipitation fell in the study area, i.e. none over the period 17–21 October, and only 0.5 mm rainfall on 22 October, between 16.00 h and 18.00 h. However, on the 23 October a total of 4.2 mm rain fell in the area, this occurring between 24.00 h and 10.00 h. A summary of daily precipitation and temperature values are presented in table 1.

One effect of the heavier precipitation remained visible after the rainfall had ceased: the flow of rain water across certain areas of exposed soil, such as recently ploughed/harrowed fields, pathways and access tracks, had produced a smooth muddy substrate so providing an ideal medium for investigating the surface movements of organisms. In particular, the above ground movements of earthworms were evident as long, winding impressions left behind as the animals moved across the soft substrate. Consequently, both the axis of movement and the distance of travel could be ascertained for each of the earthworm trails.

Table 1. Total precipitation and mean soil temperature (5 cm depth) at Foulum

Date	Precipitation [mm]	Soil temperature [°C]	
		Grass cover	Bare soil
21 Oct. 1987	0	9.8	9.0
22 Oct. 1987	0.5	9.9	9.5
23 Oct. 1987	4.2	9.7	9.1
24 Oct. 1987	0.1	7.9	5.5

One area of exposed soil afforded a particularly good substrate, this being a track, 8.7 m wide, which was situated between the experimental fields. A section of the track, 130 m in length, was investigated. To either side of the track were fields of different agricultural practice, viz. rye grass on the northern side and clover/grass adjacent to harrow on the southern side. At the time of examination of the earthworm trails, each field was assumed to have undergone a uniform agricultural treatment, but subsequent details regarding management of the fields proved this to be incorrect. The clover/grass field could, in fact, be divided into two halves, 1-year and 2-year old, respectively. As well as this maturity difference, the 1-year old section had been sprayed with a pyrethroid pesticide 'Cymbush' (aimed at controlling the weevil *Sitona lineatus* L., 1761) on the 23 September, one month prior to our investigation.

From the dimensions of the earthworm trails (especially the width of up to 10 mm), as well as the presence of characteristic surface casts, the earthworms involved could have been large individuals of either *L. terrestris* or *Aporrectodea longa* UDE, 1886. However, from subsequent night-time observations of surfaced earthworms in the study area, the species involved was almost certainly *L. terrestris*. The overall length of each trail was estimated by tracing the various turns and loops of the trail using coloured string. The total length of string was then measured to the nearest 0.1 m. The end points of each trail were taken as entry into a worm burrow, discontinuity due to foot/tractor prints, or disappearance towards the track's borders. Thus, trail measurements are conservative, representing minimum values for distances travelled over the track. From visual observations, however, it was obvious that many trails (over 50%) extended further into the fields on either side of the track. In addition to measuring trail length, the form of the trails and their distribution along the track were also recorded. In all, a total of 30 earthworm trails were found and examined.

3. Results

The 30 earthworm trails located along the 130 m by 8.7 m section of the track are depicted in fig. 1. For all trails, the mean minimum length, which represents the mean minimum measured distance of crawling over the track, is 9.0 m (s.d. = 3.8 m). The range of distance is 3.8 m to 19.3 m, with 37% of the trails being greater than 10 m. The frequency distribution of the minimum lengths of the trails is presented in fig. 2.

From examination of the form of the earthworm trails (i.e. for each trail, consideration of deviations from main trail axis) it could be estimated that 33% represented a fairly direct movement across the track, the remaining 67% representing circuitous movements of varying complexity. As far as could be ascertained, burrows were associated with 30% of the trails, 7% having a burrow at either end. Furthermore, it was observed that many trails crossed each other, and some even merged on occasion such that two trails were superimposed for a distance. Also, for some trails the outward journey was retraced during the return journey, a loop occurring at the turning point.

Regarding distribution pattern, it is apparent from fig. 1 that the earthworm trails are not uniformly distributed along the length of the track, 20% of the trails occurring opposite the 50 m of 1-year clover/grass, 70% opposite the 50 m of 2-year clover/grass, and 10% opposite the 30 m of harrowed field. A comparison of trail frequencies along the two equal-length areas of clover/grass indicates a significant difference ($P < 0.05$, Chi-squared test) between the 1-year and 2-year areas.

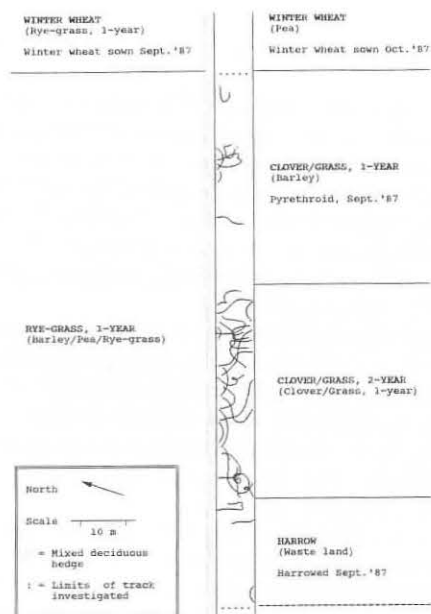


Fig. 1. Plan of the study area, showing the track plus earthworm trails, and the adjacent agricultural fields. For each field, current agricultural practice is indicated in bold type and the previous year's practice in brackets. Further details of field management are also provided.

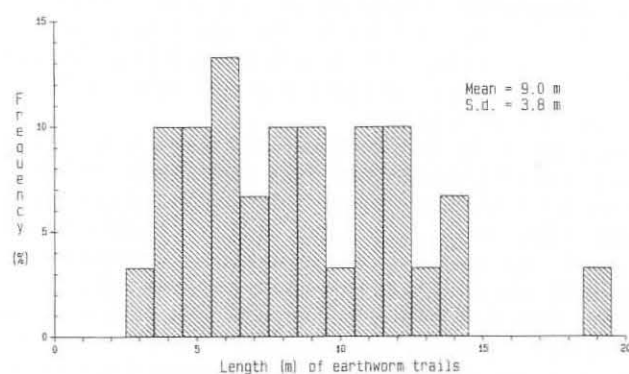


Fig. 2. Frequency (%) distribution of earthworm trail length (m), plotted at 1 m increments.

4. Discussion

It is clear from our investigation that when above ground, individual *L. terrestris* earthworms are capable of travelling considerable distances, as demonstrated by the earthworm trail a minimum of 19 m in length. Such surface activity becomes even more impressive when we take into account the fact that for the majority of earthworm trails examined, each was only a part of the total journey travelled and, probably, each represents a single diem's foray. Such data illustrate important aspects of earthworm behaviour: (1) their ability to explore and sample surrounding areas; and (2) their ability to migrate rapidly between habitats of differing suitability. These findings have relevance for studies of earthworm population dispersal and distribution, in that they draw attention to the

potential of earthworms for swift emigration/immigration, and therefore colonisation of new habitats.

Having demonstrated that *L. terrestris* is capable of moving considerable distances over the surface of the ground, we must now consider the reasons underlying this above ground activity.

The migration of animals within or between habitats may occur for a variety of reasons. For example, local or longer distance movements may be part of the individual's routine (e.g. diel/seasonal) resource-seeking activity aimed at food, mates and shelter. Besides this routine activity, movement away from an area may be due to a lowering suitability of the local habitat resulting from environmental pressures such as over-population, predation and natural/anthropogenic habitat disturbance (BAKER, 1978; AIDLEY, 1981).

As far as the migratory behaviour of earthworms is concerned, it is known that *L. terrestris* exhibits a diel vertical migration, individuals moving through their burrow systems up to the surface at night to feed, defaecate and mate, and then moving down beneath the surface again to spend the day. Surface activity is dependent upon ambient weather conditions; the optimum temperature for activity is about 10°C, emergence tending not to occur at temperatures below 2°C, and some precipitation should have fallen during the previous few days (KOLLMANN-SPERGER, 1955; SATCHELL, 1967; MACDONALD, 1983).

From subsequent night-time observations of the track and adjacent fields in our study area carried out at 22.00h on 24 October (soil temperature at 5 cm depth beneath grass and bare soil being 7.6°C and 4.5°C, respectively; no precipitation), above ground activity of *L. terrestris* was evident. Dim torch light revealed several adult, sub-adult and large juvenile individuals crawling over the surface of the fields, and copulating pairs were also visible. In view of these observations of apparently healthy earthworms, it is plausible that some of the earthworm trails we examined had been made by normal individuals and represent emergence due to routine (diel) activity aimed at resources such as food and mates.

Besides this routine surface activity by individual earthworms, a variety of mass migrations are also reported in the literature. Concerning the lumbricids, widely known is the mass emergence of earthworms from their burrows onto the surface during and following rainfall or heavy dew, this phenomenon first being described by DARWIN in 1881. FRIEND (1924) also noted an association between mass emergence and periods of cool, moist weather, as typically occur during the autumn, winter and spring months.

In an attempt to account for the phenomenon of mass emergence of earthworms during and following precipitation, several proposals have been made which imply that earthworms are forced to surface as a result of hostile habitat conditions, such as oxygen depletion (LANKESTER, 1921; MERKER, 1926, 1928; NISHIDA, 1951) or hydrogen sulphide concentration (DOEKSEN, 1967) in the soil due to rain saturation. In contrast to these proposed negative effects of precipitation on earthworms, positive effects have also been considered which imply that moisture resulting from rainfall or heavy dew may not only promote surface activity but may even facilitate resource-seeking. SVENDSEN (1957), for example, reports that several lumbricid species aggregate in dung as a result of movement at or near the soil surface during moist conditions. This finding has led to the proposal that some species actively search for food sources during periods of rainfall.

Concerning the present investigation, it is known that rain had fallen during the night preceding observations. In view of the above proposals, it is possible that the earthworm trails here examined represent a mass emergence of earthworms which had surfaced primarily as a result of the rainfall. Whether surfacing was due to the favourable or the adverse effects of precipitation cannot be determined, though the former would suggest trails made by normal individuals during enhanced resource-seeking activity, and the latter by stressed individuals attempting to escape adverse habitat conditions.

It could be considered that the two aforementioned possibilities, i.e. (1) emergence of some individuals due to routine (diel) activity and (2) mass emergence due to rainfall, may well account for the occurrence of earthworm trails examined. However, remaining unexplained is the non-uniform distribution pattern of trails along the length of the track, a significantly higher and more even density occurring opposite the 2-year old clover/grass field. This distinct bias in the

distribution pattern of trails along the path suggests that an additional factor relating to agricultural practice is also involved, its effect being superimposed on other more general effects.

It is known that earthworm density tends to build up with decreased cultivation and increased organic matter (EDWARDS, 1980). Thus, the difference in the distribution pattern of earthworm trails we found may be due to the activity of a higher density of earthworms in the 2-year old field. Alternatively, it cannot be discounted that the use of the pyrethroid pesticide on the 1-year old field had some deleterious effect on the local earthworm population, perhaps causing a decrease in density due to death and/or emigration prior to our investigation.

The lower density of earthworm trails opposite the recently harrowed field may also result from agricultural practice. Cultivation by mechanical disturbance is known to affect a proportion of the earthworm population by destroying the environment, by damaging and killing the earthworms, and also by bringing them to the surface where they are preyed on by birds (EDWARDS, 1983; CUENDET, 1983). In agreement with this, day-time observations concomitant with our investigation revealed several dead and dying *L. terrestris*, partly or completely emerged on the surface of the harrowed field.

Regardless of causal factors for the distribution pattern of earthworm trails along our investigation track, however, the fact remains that trail distribution correlates with habitats of differing agricultural practice.

With regard to agricultural practice, modern methods are having an increasing impact on the environment (see discussion by HILL & KEVAN, 1987). In particular, the use of pesticides and fertilisers is of growing concern because of their harmful side-effects on ecosystems. Such interference ultimately results in areas of ecological imbalance and stress which may take many years to recover or may even be irreversibly altered. As this poses a serious environmental problem, it is vital to recognise the first symptoms of ecological stress.

Certain organisms, generally referred to as 'bio-indicators', are now proving to be useful tools for the biological identification and measurement of ecological stress in the environment (SCHUBERT, 1985; SOULE & KEPPEL, 1987). By monitoring such indicator organisms it can be shown, for example, that changes in population and community structure reflect changes in habitat conditions. Earthworms are amongst those organisms frequently considered as bio-indicators for terrestrial ecosystems (KÜHLE, 1983; CHRISTENSEN *et al.*, 1987).

The findings of our investigation have led us to consider further this concept of environmental monitoring through bio-indication. The association between earthworm surface movements and agricultural practice suggests that the movement patterns of certain indicator species may well prove to have application in this respect. We here wish to propose, therefore, that in addition to monitoring such parameters as population structure and density, movement patterns should also be viewed as a possible parameter of measurement for bio-indication. The use of such a parameter has considerable advantage over others currently used: on the one hand, the method of measurement is fairly non-disturbing for the indicator organism and yet is convenient for the experimenter; on the other hand, the measured response is relatively sensitive and immediate, so providing an early warning of changing conditions.

In particular, we propose that earthworm surface movement patterns have potential as a sensitive and convenient method for indicating the condition and quality of soil habitats, in that: (1) the average number of trails per unit area over time can be used to derive a general index of activity which so gives an indication of population density. This has application for monitoring the short- and long-term ecological effects of changes in habitat conditions, such as results from agricultural practice (application of pesticides and fertilisers, employment of various cultivation techniques, etc.); (2) the directional aspect of earthworm movement can both indicate the present condition and help to predict the future condition of habitats, e.g. emigration and immigration suggesting a relatively decreasing and increasing suitability of habitats, respectively.

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The dispersal rates of earthworm populations within the soil habitat have previously been considered, especially in relation to the colonisation of grass land. However, even though the most rapid and effective mode of population spread is likely to occur across, rather than below, the soil surface, quantitative data concerning the distances travelled by individual earthworms when above ground remain sparse.

Here, the surface trails of earthworms in agricultural land are investigated and it is demonstrated that individuals of *Lumbricus terrestris* are able to cover considerable distances (ranging from 3.8 m to 19.3 m) during a single surface foray. The data illustrate important aspects of earthworm behaviour, particularly their ability to explore and sample surrounding areas, as well as their potential for migrating rapidly between habitats of varying suitability and for colonising new areas.

Furthermore, the investigation suggests that earthworm surface trails can be related to agricultural practice. Thus, it is here proposed that surface movement patterns have potential as a sensitive and convenient method for indicating the short- and long-term ecological effects of changes in habitat conditions. This proposal has application for the concept of environmental monitoring through bio-indication.

Key words: Earthworms, surface trails, exploration, migration, agricultural practice, habitat suitability, bio-indication.

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